

TITLE

Alterations to the orientation of the ground reaction force vector affect sprint acceleration performance in team sports athletes

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2 performance in team sports athletes

3

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12

13 *Running title:* GRF orientation and acceleration performance

14

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28 *Abstract:*

29 A more horizontally oriented ground reaction force vector is related to higher levels of sprint
30 acceleration performance across a range of athletes. However, the effects of acute experimental
31 alterations to the force vector orientation within athletes is unknown. Fifteen male team sports
32 athletes completed maximal effort 10 m accelerations in three conditions following different verbal
33 instructions intended to manipulate the force vector orientation. Ground reaction forces were
34 collected from the step nearest 5 m and stance leg kinematics at touchdown were also analysed to
35 understand specific kinematic features of touchdown technique which may influence the
36 consequent force vector orientation. Magnitude-based inferences were used to compare findings
37 between conditions. There was a likely more horizontally oriented ground reaction force vector and
38 a likely lower peak vertical force in the control condition compared with the experimental
39 conditions. 10 m sprint time was very likely quickest in the control condition which confirmed the
40 importance of force vector orientation for acceleration performance on a within-athlete basis. The
41 stance leg kinematics revealed that a more horizontally oriented force vector during stance was
42 preceded at touchdown by a likely more dorsiflexed ankle, a likely more flexed knee, and a
43 possibly or likely greater hip extension velocity.

44 *Introduction*

45 Sprint acceleration is a fundamental component of team sports (Duthie, Pyne, Marsh, & Hooper,
46 2006; Varley & Aughey, 2013). This ability to rapidly increase whole body velocity is often
47 measured as the time taken to cover a short distance from a stationary position. Effective
48 acceleration requires the generation of large ground reaction forces (GRFs) in ground contact
49 times typically less than 200 ms (Rabita et al., 2015), and physical capabilities such as concentric
50 strength and power have thus been shown to be related to sprint acceleration performance in team
51 sports athletes (Cunningham et al., 2013; McBride et al., 2009; Sleivert & Taingahue, 2004).
52 However, these relationships are typically only moderately strong and the remaining variation in
53 sprint acceleration performance is seldom further explained by additional physical capabilities
54 (Cronin & Hansen, 2005; Cunningham et al., 2013; Sleivert & Taingahue, 2004).

55

56 Recent evidence suggests that some or all of the additional variation in sprint acceleration
57 performance could be explained by technical ability. Descriptive and regression-based studies
58 demonstrate that higher performing accelerators within similar participant groups (the analysed
59 groups range between studies from physical education students to elite sprinters) do not produce
60 greater magnitudes of resultant GRF, instead they direct the resultant GRF vector in a more
61 horizontal direction (Kawamori, Nosaka, & Newton, 2013; Kugler & Janshen, 2010; Morin,
62 Edouard, & Samozino, 2011; Rabita et al., 2015; Slawinski et al., 2016). This technical ability has
63 been quantified by calculating the ratio of forces (RF; Morin et al., 2011) which expresses the
64 horizontal (antero-posterior) component of the GRF vector as a percentage of the total (two-
65 dimensional) GRF vector magnitude. These studies suggest that provided sufficient GRF
66 magnitude can be produced, at broadly similar performance levels the technical ability of producing
67 a higher RF is of greater importance than the physical capability of producing larger GRFs for
68 sprint acceleration performance. However, whilst the importance of this higher RF has been
69 demonstrated between participants in group-based and cross-sectional studies, experimental
70 within-participant research is required to strengthen the case for a causal relationship (Bishop,
71 2008).

72

73 In order to acutely manipulate RF within-participants, aspects of sprint acceleration technique
74 which potentially underlie it must be identified. This would not only allow an experimental study to
75 be effective in acutely manipulating RF, it could also provide novel insight regarding specific
76 kinematic features of technique which could be targeted to affect RF. Although specific features of
77 technique which underlie the ability to produce a high RF remain unclear, existing sprint
78 acceleration research provides some direction. Slawinski et al. (2016) found that the use of
79 different start positions affected RF during the initial push-off phase from stationary, but RF was
80 not reported from the subsequent steps. Jacobs and van Ingen Schenau (1992) analysed the
81 second stance phase of a maximal effort sprint and identified a general lower-body strategy in
82 which highly-trained sprinters delayed extension of the centre of mass (CM) away from the centre
83 of pressure until they had first rotated the CM further forwards. This yielded a greater horizontal
84 component of the subsequent extension of the CM away from the centre of pressure, more
85 favourable given the horizontal translational demands of sprint acceleration. Kugler and Janshen
86 (2010) analysed the first stance phase of physical education students from both a standing start
87 and the second or third accelerative stance following a flying start. They found the CM of the higher
88 performing accelerators within the group to be further forward relative to their centre of pressure
89 when averaged over stance compared with the lower performing half of the cohort. These superior
90 accelerators achieved this by placing their stance foot further back relative to their CM at
91 touchdown or by prolonging ground contact time. This alteration in lower body kinematics at
92 touchdown directly impacts the strategy outlined by Jacobs and van Ingen Schenau (1992); if the
93 stance foot is further back relative to the CM at touchdown then less forwards rotation is required
94 before extension can contribute to a given horizontal translation of the CM. Such a strategy was
95 recently theoretically confirmed using a computer simulation of a sprinter during the first stance
96 phase whereby systematically placing the foot further back at touchdown relative to the CM led to a
97 near linear increase in RF during the ensuing stance phase (Bezodis, Trewartha, & Salo, 2015).
98 Finally, in one of the few within-participant comparisons of sprint acceleration to date, where trials
99 with high and low braking forces at 16 m were compared within individuals among a group of 36
100 track and field and team sports athletes (Hunter, Marshall, & McNair, 2005), the stance foot was
101 less far ahead of the CM at touchdown in the trials with lower braking impulses.

102

103 The placement of the stance foot relative to the CM at touchdown appears to be a potentially
104 important feature of technique during sprint acceleration. However, it must be considered that the
105 stance leg is multi-segmental and therefore the relative location of the stance foot is primarily
106 determined by the angles of the stance hip, knee and ankle joints. Furthermore, in addition to
107 landing with the stance foot less far ahead of the CM to exaggerate the strategy outlined by Jacobs
108 and van Ingen Schenau (1992), this strategy could also be exaggerated by rotating the CM ahead
109 of the stance foot more rapidly. The angular velocity with which the hip, knee and ankle are rotating
110 at touchdown may therefore be another kinematic feature of technique of interest. In addition to
111 solely considering the placement of the stance foot relative to the CM, investigation of the stance
112 leg joint angles and angular velocities at touchdown could provide valuable insight regarding more
113 specific kinematic features of technique which may be important for achieving a high RF. We
114 therefore aimed to acutely manipulate the ratio of forces produced by team sport athletes during
115 acceleration and identify how this affected overall sprint acceleration performance, and to identify
116 and understand any kinematic features of technique associated with a higher ratio of forces.

117

118

119 *Methods*

120 The study was approved by the University Research Ethics Committee and 18 male team sport
121 (Gaelic football, rugby union, soccer) athletes (mean \pm SD: age = 22 ± 4 years, mass = $78.2 \pm$
122 10.5 kg, height = 1.76 ± 0.10 m) provided written informed consent to participate. Participants
123 completed three 10 m sprints from a standing start in each of three counterbalanced conditions.
124 Given the widespread use of verbal technical instructions in sprint coaching, different verbal
125 instructions were provided immediately prior to each sprint in an attempt to manipulate ratio of
126 forces between the three conditions. These instructions were based on the well-established motor
127 learning manipulation of attentional focus (see Wulf, 2013 for a review) where internally and
128 externally focussed instructions are used to direct a performer's attention towards either their
129 movements (internal focus) or the effect of these movements on the environment (external focus).
130 Attentional focus research has consistently demonstrated that manipulating verbal instructions is

131 an effective means through which to acutely alter technique and performance outcome (Wulf,
132 2013), including during maximal effort vertical and horizontal jumping (Porter, Ostrowski, Nolan, &
133 Wu, 2010; Wulf & Dufek, 2009) where GRF production is a key determinant of performance, as it is
134 for sprint acceleration.

135

136 In all conditions, participants were instructed to "complete the 10 m sprint as quickly as possible".
137 No further instructions were given in the control condition. For the internal focus condition, the
138 instructions continued with "whilst focussing on pulling your leg backwards just before each contact
139 with the ground". For the external focus condition, the instructions continued with "whilst focussing
140 on clawing backwards at the ground with your shoe in every step you take". These instructions
141 were designed to affect lower-limb action at touchdown in line with our rationale. They were based
142 on the recommendations of Wulf (2013) in that they were purposefully similar in content and
143 amount of information provided, focussed on the same aspect of the movement, and only differed
144 in whether attention was directed internally (the leg) or externally (the ground). As proposed by
145 Peh, Chow and Davids (2011), all participants completed a written manipulation check after each
146 condition to verify whether their self-reported attentional focus matched that of the intended
147 experimental condition. Qualitative analysis of these data led to the removal of three participants
148 who reported attentional foci which conflicted with one or more of the intended experimental
149 conditions (i.e. $n = 15$ for all subsequent quantitative analyses). Participants were not provided with
150 augmented feedback at any time; they were unaware of their sprint times and were given no
151 feedback regarding their movements.

152

153 All sprints were completed in a 30 m indoor laboratory in training shoes on a rubber track following
154 a self-directed warm-up. All sprints were initiated by the participant and commenced from a
155 standing two-point start with one foot ahead of the other just behind a set of timing lights (TC
156 Timing System, Brower, USA). A second set were located 10 m away to determine sprint
157 acceleration performance. Where necessary, the exact location of both timing lights was adjusted
158 slightly (the exact distance between them always remained at 10 m) to ensure that complete GRFs
159 from the ground contact closest to the 5 m mark were recorded (960 Hz) from an embedded $0.9 \times$

160 0.6 m force platform (9287BA, Kistler, Switzerland) without any targeting from the participants. For
161 some athletes, up to five sprints were required in a given condition to successfully obtain GRF data
162 for three sprints. Thirty-eight reflective markers were attached to each participant at specific
163 locations. Markers at the anterior and posterior superior iliac spines, greater trochanters, medial
164 and lateral aspects of the knee joint centre, medial and lateral malleoli, and first and fifth
165 metatarsal-phalangeal joint centres were used to define the seven segments (pelvis, 2 × thigh, 2 ×
166 shank, 2 × foot) from a static trial. Additional markers (in clusters on the thighs and shanks) were
167 also attached for this static trial and were subsequently used to track these segments using a
168 CAST approach (Cappozzo, Catani, Della Croce, & Leardini, 1995) during the sprint acceleration
169 trials. Marker trajectories were tracked (240 Hz) using an 11-camera motion capture system (MX-3,
170 Vicon, UK) and collected alongside synchronous GRF data using Nexus (v. 1.8.5, Vicon, UK). The
171 raw marker trajectories were labelled in Nexus before all data were exported for analysis in
172 Visual3D (v. 5.01, C-Motion Inc., USA).

173

174 Marker trajectories were low-pass filtered using a 4th order Butterworth digital filter at 20 Hz and
175 segmental kinematics were reconstructed from the tracking markers using an evenly-weighted
176 inverse kinematics procedure (Lu & O'Connor, 1999). For the ground contact on the force platform,
177 touchdown and toe-off were identified from the raw vertical GRF data (10 N threshold) and
178 flexion/extension angles (Cardan X-Y-Z, expressed relative to the static trial in neutral standing)
179 and angular velocities (resolved in the proximal segment) were calculated and identified at
180 touchdown. Where touchdown occurred between frames of kinematic data, linear interpolation was
181 used to obtain a closer representation of the true touchdown value. The antero-posterior velocity of
182 the stance foot CM at touchdown was extracted as foot touchdown velocity, and the antero-
183 posterior distance between the stance foot CM and the pelvis CM at touchdown was calculated
184 (hereafter termed touchdown distance; a positive value represents foot ahead of pelvis). Peak and
185 average GRFs during stance were identified and divided by body weight, and impulses were
186 determined using the trapezium rule and divided by body mass to yield changes in velocity. Ratio
187 of forces was calculated using the previously described procedures of Morin et al. (2011). Toe-off
188 from the stance phase prior to that on the force platform was determined when the vertical position

189 of the 5th metatarsal-phalangeal marker first exceeded 0.1 m (Lees, Steward, Rahnama, & Barton,
190 2009), and flight time from this step was determined. Step length for this step was calculated from
191 the antero-posterior coordinates of the 5th metatarsal-phalangeal markers at adjacent toe-off
192 events.

193

194 For all dependent variables, the mean value for each participant was calculated from the three
195 trials for each condition. A repeated measures ANOVA was conducted for each dependent variable
196 to identify whether a significant ($p < 0.05$) main effect of experimental condition was present. For
197 all variables where a significant main effect was observed, the pairwise differences were then
198 analysed using a magnitude-based inference approach (Batterham & Hopkins, 2006; Hopkins,
199 2006). Effect size statistics (Cohen's d ; Cohen, 1988) were calculated between each of the three
200 pairs of conditions, and 97% confidence intervals (to remain conservative due to three pairwise
201 comparisons) were calculated to quantify the uncertainty of these effect sizes (Hopkins, 2006). The
202 smallest worthwhile change was determined as an effect size of 0.2 (Hopkins, 2004; Winter, Abt, &
203 Nevill, 2014) which also standardised the interpretation between variables in different units. This
204 allowed the percentage likelihood that each effect was negative, trivial, and positive to be
205 determined, from which qualitative, mechanistic magnitude-based inferences were made (Hopkins,
206 2006).

207

208

209 *Results*

210 There was a significant main effect of experimental condition on RF and sprint acceleration
211 performance (i.e. 10 m sprint time; Table 1). Ratio of forces was likely lower (i.e. a more vertically
212 directed GRF vector) in both the internal and external focus conditions compared with the control
213 condition (by $1.7 \pm 1.7\%$ and $1.3 \pm 1.1\%$, respectively (mean \pm 97% confidence interval)), whilst the
214 difference between the internal and external focus conditions was unclear (Figure 1a, Table 2).
215 The 10 m sprint times were very likely longer (i.e. a lower level of performance) in both the internal
216 and external focus conditions compared with the control condition (by 0.056 ± 0.036 s and $0.056 \pm$
217 0.042 s, respectively), whilst the difference between the internal and external focus conditions was

unclear (Figure 1b, Table 2). When looking in greater detail at the GRF data, there was no significant main effect of experimental condition on the peak or average resultant force or its horizontal component but there was a main effect on the peak vertical GRF magnitude (Table 1). Peak vertical GRF was very likely greater in the internal focus condition compared with the control condition (by 0.17 ± 0.10 BW), likely greater in the external focus condition compared with the control condition (by 0.09 ± 0.08 BW), and possibly smaller in the external focus condition compared with the internal focus condition (by 0.08 ± 0.09 BW; Figure 1c, Table 2). There was no significant main effect of experimental condition on any of the horizontal impulses (braking, propulsive or net propulsive) but there was a main effect of condition on vertical impulse (Table 1). Vertical impulse was very likely greater in both the internal and external focus conditions compared with the control condition (by 0.08 ± 0.07 m/s and 0.06 ± 0.04 m/s, respectively), whilst the difference between the internal and external focus conditions was unclear (Figure 1d, Table 2).

230

****Table 1 near here****

****Table 2 near here****

****Figure 1 (a-g) near here****

234

Regarding the kinematics at the instant of touchdown, there was a significant main effect on ankle angle, knee angle and hip angular velocity (Table 1). The ankle was very likely more plantar flexed at touchdown in the internal focus condition compared with the control condition (by $3.3 \pm 2.1^\circ$), likely more plantar flexed at touchdown in the external focus condition compared with the control condition (by $2.5 \pm 2.2^\circ$), whilst the difference between the internal and external focus conditions was likely trivial (Figure 1e, Table 2). The knee was likely more extended at touchdown in both the internal and external focus conditions compared with the control condition (by $2.1 \pm 2.0^\circ$ and $1.6 \pm 1.7^\circ$, respectively), whilst the difference between the internal and external focus conditions was unclear (Figure 1f, Table 2). Hip extension angular velocity was likely slower in the internal focus condition compared with the control condition (by $49 \pm 39^\circ/\text{s}$), possibly slower in the external focus condition compared with the control condition (by $33 \pm 49^\circ/\text{s}$), and possibly faster in the external focus condition compared with the internal focus condition (by $15 \pm 39^\circ/\text{s}$; Figure 1g, Table 2).

247 There was no significant main effect of experimental condition on the other investigated joint
248 angular kinematics at touchdown, nor on touchdown distance, foot touchdown velocity, or the
249 preceding step length and flight time (Table 1).

250

251

252 *Discussion*

253 We aimed to acutely manipulate the ratio of forces produced by team sport athletes and quantify
254 the effects on sprint acceleration performance, as well as identifying and understanding specific
255 kinematic features of technique associated with a higher ratio of forces. For all variables where
256 significant main effects of condition were observed, the internal and external focus conditions both
257 yielded similar responses compared with the control condition (Table 2). Given the aim of this
258 study, and the fact that both experimental conditions elicited similar changes in 10 m sprint time,
259 GRFs and joint kinematics, this discussion will solely focus on the differences between the
260 combined experimental conditions and the control condition.

261

262 Sprint times were very likely quickest in the control condition where RF was likely highest. This
263 provides new experimental support for previous descriptive (Kugler & Janshen, 2010; Rabita et al.,
264 2015) and regression-based (Kawamori et al., 2013; Morin et al., 2011; Slawinski et al., 2016)
265 evidence which has identified the importance of a more horizontally directed GRF vector in sprint
266 acceleration performance. Our results demonstrate the importance of this technical ability in an
267 acute, within-participant design, and suggest that striving to improve RF within individual team
268 sports athletes through acute technical alterations may be a beneficial strategy for improving sprint
269 acceleration performance. As there was no effect of condition on the peak or average resultant
270 GRF, our results also provide further support for the relative lack of importance of the magnitude of
271 the resultant GRF vector. The observed changes in RF occurred primarily due to an increased
272 peak in the vertical component of the GRF, which led to an increase in vertical impulse given that
273 stance duration did not differ between the conditions. During sprint acceleration it has been
274 suggested that provided sufficient impulse is directed vertically to allow time for the legs to be
275 repositioned during flight in preparation for the next ground contact, all of the remaining force

276 should be applied horizontally (Hunter et al., 2005). As the increases in vertical impulse in the
277 current study occurred in the conditions in which performance levels were lower, it thus appears
278 that these increases were not necessary and negatively affected performance.

279

280 The changes in RF and sprint performance between conditions were also accompanied by
281 changes in angular kinematics at touchdown, and these provide evidence of kinematic features of
282 technique which may be associated with RF. In the control condition, the ankle was likely or very
283 likely in a more dorsiflexed position, the knee in a likely more flexed position, and the hip possibly
284 or likely extending more rapidly, compared with the experimental conditions. The larger mean
285 differences and effect sizes for the ankle angle compared with the knee suggest that participants
286 may have prioritised greater movements at the ankle in an attempt to follow the instructions. This is
287 consistent with the findings of a systematic review of experimental running studies which identified
288 that ankle joint kinematics are altered to a greater extent than knee or hip kinematics in studies
289 designed to achieve acute technical changes in foot strike (Napier, Cochrane, Taunton, & Hunt,
290 2015). It is therefore possible that alterations to ankle joint kinematics may have been the intended
291 response to the experimental conditions but a concurrent increase in knee flexion compensated for
292 this, explaining the lack of observed change in touchdown distance. Although touchdown distance
293 was earlier proposed as a mechanism that could be important for determining RF, the current
294 findings suggest that touchdown distance *per se* may not be a determining factor in RF but that
295 specific joint configurations within the stance leg may be important. Previous research which has
296 proposed the importance of touchdown distance for RF has either not reported the stance leg joint
297 kinematics (Kugler & Janshen, 2010; McNitt-Gray et al., 2015), or has theoretically manipulated
298 specific joint kinematics to achieve changes in touchdown distance (Bezodis et al., 2015). It is
299 possible that greater ankle dorsiflexion and/or knee flexion at touchdown may help to acutely
300 increase RF either directly due to body configuration or indirectly due to effects on related factors
301 such as muscle-tendon unit lengths. Whilst we cannot determine this from the current repeated-
302 measures group comparison, these findings provide experimental evidence of specific joint angular
303 kinematics that are worthy of further cross-sectional, experimental or theoretical investigation for
304 understanding the determinants of RF. Hip extensor velocity has been suggested to be important

305 during maximum velocity sprinting (Mann & Sprague, 1983) and the possible or likely change in hip
306 extension angular velocity observed in the current study suggests that it may also be important for
307 early acceleration. This finding is also potentially interesting in the context of recent evidence
308 regarding the potential importance of the torque producing capability of the hip extensors and
309 hamstring activity just prior to touchdown for horizontal force generation in sprint acceleration
310 (Morin et al., 2015). However, given the magnitude of the effects observed in this study and the
311 lower likelihood of this difference at the hip joint compared with other observed differences, further
312 evidence is required in support of this finding.

313

314 Whilst the majority of the effects observed in this study were small, this is unsurprising given the
315 well-established movement pattern being studied and the nature of the intervention. These small
316 effects on technique and performance are meaningful in applied practice in team sports where
317 fractions of a second can make the difference to, for example, reaching an opponent or getting to a
318 ball first. This study has therefore demonstrated clear scope for, and potential value in, further
319 investigation of acute manipulations to touchdown technique. It is important to note that
320 performance levels were very likely highest in the control condition where participants were simply
321 instructed to “sprint as quickly as possible”. Our findings therefore confirmed previous evidence
322 (Kawamori et al., 2013; Kugler & Janshen, 2010; Morin et al., 2011; Rabita et al., 2015) and
323 extended it on a within-participant basis, but they did not specifically identify that performance
324 could be acutely improved relative to current levels. This very likely decrease in performance in
325 both experimental conditions compared with the control condition initially appears to conflict with
326 findings reported in the motor learning literature where attentional focus has been manipulated
327 (see Wulf, 2013). Although not elite, all of our participants had been involved in team sports since
328 adolescence and their sprint acceleration movement patterns were therefore likely to be highly
329 automated. The majority of research that has demonstrated superior performance for participants
330 adopting an external focus of attention has typically studied novice and inexperienced performers
331 who would be at earlier stages of learning (Newell, 1985; Peh et al., 2011), and in one of the few
332 studies where truly expert performers have been studied, both an external and internal attentional
333 focus were found to negatively affect automaticity of movement compared to a control condition

(Wulf, 2008). This may explain why both internal and external focus conditions acutely led to a very likely reduction in performance in comparison with the control condition in our study. We intentionally used instructions grounded in an established theory to investigate this issue because of the exploratory nature of this study and because attentional focus manipulations have been widely shown to be effective in altering technique and performance outcome in numerous motor skills (Wulf, 2013). Technical alterations in an applied coaching environment have been suggested to acutely increase horizontal impulse production and/or favourably affect touchdown distance (McNitt-Gray et al., 2015), but specific details were not provided, and manipulations to the starting posture of an athlete may also provide a means through which to attempt to manipulate RF (Slawinski et al., 2016). Future applied work to understand the effects of more commonly adopted coaching instructions which could facilitate acute enhancements in performance, and investigation of the kinematic features of technique which they affect, is clearly required. The use of data-rich environments in combination with experiential coaching knowledge offers exciting potential for the future exploration of the efficacy of such acute manipulations. We also used a group-based design which did not consider the individual anthropometric or strength characteristics of the athletes, and it is possible that these could influence the specific strategy which is optimal for achieving a higher ratio of forces for a given individual. Future studies could therefore attempt to consider the combined influence of individual structure and changes in technique on any observed changes in sprint acceleration performance.

353

In summary, this study acutely manipulated the ratio of forces produced by team sports athletes during acceleration using verbal instructions. Performance levels were highest in the condition where ratio of forces was highest which aligns with recent evidence and extends it on a within-participant basis. Differences in lower limb angular kinematics were also evident at touchdown between conditions, with greater ankle dorsiflexion, greater knee flexion and increased hip extension velocity evident when RF and performance were higher. Attempts to alter RF within individuals appears to be a worthwhile strategy for coaches and scientists to pursue, and these specific kinematic features of technique provide potential mechanisms worthy of further investigation in both acute manipulations and longer-term technical or physical interventions.

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 475 Wulf, G., & Dufek, J. S. (2009). Increased jump height with an external focus due to enhanced
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477 Table 1. Mean \pm SD for all dependent variables from each condition and main condition effects
 478 from the repeated measures ANOVA.

Variable	Units	Group mean \pm SD			Main condition effect (p)
		C	I	E	
Ratio of forces	%	25.2 \pm 2.5	23.5 \pm 3.1	23.9 \pm 2.2	0.02
10 m sprint time	s	1.936 \pm 0.095	1.992 \pm 0.120	1.992 \pm 0.112	<0.01
Step length	m	1.37 \pm 0.10	1.42 \pm 0.10	1.41 \pm 0.10	0.06
Flight time	s	0.076 \pm 0.013	0.084 \pm 0.017	0.081 \pm 0.016	0.12*
Touchdown distance	m	0.115 \pm 0.040	0.124 \pm 0.040	0.128 \pm 0.047	0.22
Foot touchdown velocity	m/s	1.31 \pm 0.61	1.09 \pm 0.74	1.14 \pm 0.67	0.36
Ankle angle at touchdown	°	1.6 \pm 3.2	-1.6 \pm 4.4	-0.9 \pm 4.4	<0.01
Knee angle at touchdown	°	45.4 \pm 5.4	43.3 \pm 6.9	43.8 \pm 6.0	0.02
Hip angle at touchdown	°	40.9 \pm 8.5	40.0 \pm 11.5	41.2 \pm 10.8	0.37
Ankle angular velocity at touchdown	°/s	50 \pm 102	59 \pm 101	87 \pm 113	0.08
Knee angular velocity at touchdown	°/s	-99 \pm 139	-62 \pm 129	-36 \pm 123	0.06
Hip angular velocity at touchdown	°/s	-502 \pm 105	-453 \pm 107	-468 \pm 121	0.03
Stance duration	s	0.150 \pm 0.018	0.144 \pm 0.025	0.148 \pm 0.023	0.28
Peak resultant force	BW	2.46 \pm 0.26	2.56 \pm 0.23	2.54 \pm 0.21	0.11
Average resultant force	BW	1.63 \pm 0.11	1.68 \pm 0.10	1.66 \pm 0.12	0.12*
Peak propulsive force	BW	0.75 \pm 0.08	0.75 \pm 0.07	0.76 \pm 0.07	0.97
Peak braking force	BW	-0.53 \pm 0.23	-0.52 \pm 0.25	-0.53 \pm 0.28	0.92
Average horizontal force	BW	0.26 \pm 0.05	0.25 \pm 0.04	0.25 \pm 0.04	0.20
Peak vertical force	BW	2.43 \pm 0.26	2.60 \pm 0.30	2.52 \pm 0.22	<0.01
Average vertical force	BW	1.54 \pm 0.10	1.59 \pm 0.10	1.57 \pm 0.12	0.11*
Braking impulse	m/s	-0.04 \pm 0.02	-0.04 \pm 0.02	-0.04 \pm 0.02	0.99
Propulsive impulse	m/s	0.51 \pm 0.06	0.49 \pm 0.07	0.49 \pm 0.05	0.36
Net propulsive impulse	m/s	0.46 \pm 0.05	0.44 \pm 0.07	0.45 \pm 0.06	0.78
Vertical impulse	m/s	0.79 \pm 0.09	0.87 \pm 0.12	0.85 \pm 0.11	0.04*

479 Variables highlighted in bold are those where a statistically significant ($p < 0.05$) main effect was observed.
 480 C = control condition, I = internal focus condition, E = external focus condition
 481 * ANOVA calculated with Greenhouse-Geisser correction due to non-sphericity.
 482 Joint angles are all presented relative to the neutral standing trial. Positive angles represent dorsiflexion/flexion.
 483 Positive angular velocity values represent dorsiflexion/flexion.

484 Table 2. Mean change \pm 97% confidence intervals between each pair of conditions for the
 485 variables where a significant main effect of condition was observed.

Variable	I - C	E - C	E - I
Ratio of forces (%)	-1.7 \pm 1.7	-1.3 \pm 1.1	0.4 \pm 1.9
10 m sprint time (s)	0.056 \pm 0.036	0.056 \pm 0.042	0.000 \pm 0.037
Peak vertical force (BW)	0.17 \pm 0.10	0.09 \pm 0.08	-0.08 \pm 0.09
Vertical impulse (m/s)	0.08 \pm 0.07	0.06 \pm 0.04	-0.02 \pm 0.08
Ankle angle at touchdown (°)	-3.3 \pm 2.1	-2.5 \pm 2.2	0.8 \pm 1.6
Knee angle at touchdown (°)	-2.1 \pm 2.0	-1.6 \pm 1.7	0.5 \pm 1.4
Hip angular velocity at touchdown (°/s)	49 \pm 39	33 \pm 49	-15 \pm 39

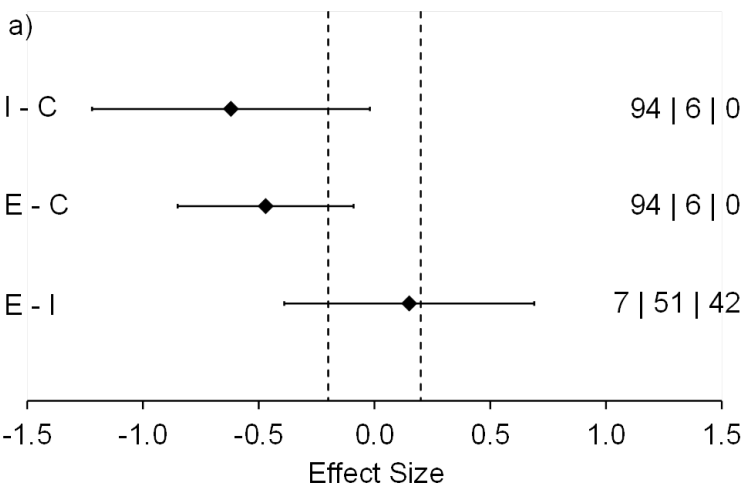
486 C = control condition, I = internal focus condition, E = external focus condition
 487 Negative changes in angle represent a more plantar flexed ankle joint and a more extended knee joint.
 488 Positive changes in angular velocity at the hip joint represent a less rapid extension velocity (i.e. a positive value is a tendency towards
 489 greater flexion velocity).
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491 *Figure legends*

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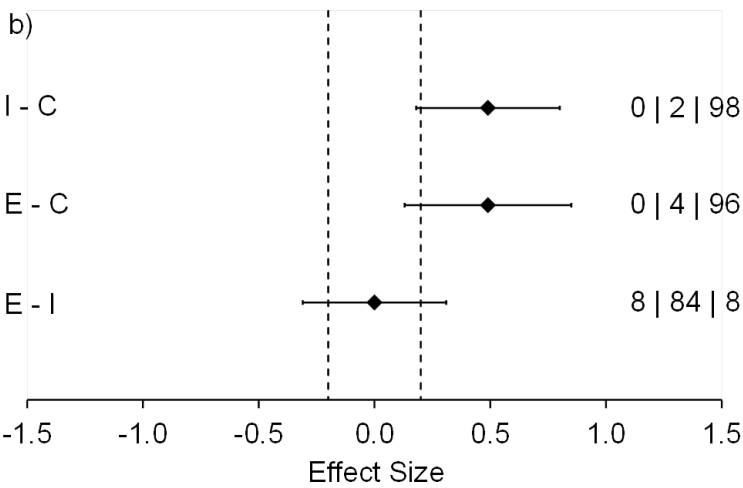
493 Figure 1. Effect sizes (with error bars representing 97% confidence intervals) between the control
494 (C), internal focus (I) and external focus (E) conditions for a) ratio of forces, b) 10 m sprint time, c)
495 peak vertical ground reaction force, d) vertical impulse, e) ankle angle at touchdown, f) knee angle
496 at touchdown, and g) hip angular velocity at touchdown. Values on the right hand side of each
497 figure provide the percentage likelihood that the effect is substantially negative | trivial | positive.

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